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The ecology of Star Swamp and surrounding bushlands, North Beach, Western Australia

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Abstract

The vegetation of Star Swamp and its surrounding catchment represents a remnant of the once extensive natural vegetation of the Swan Coastal Plain. Polar ordination techniques were used to analyze the variation in the vegetational composition of the canopy and perennial understorey strata. Size-class analysis was used to analyze the major tree species populations. The major species relationships to water levels of the swamp of soil texture, soil organic matter, soil colour and soil pH were determined. The relationship of environmental factors and the biotic effect of naturalized weedy species on species diversity was also determined.

Areas of seasonal flooding were dominated by Paperbark (*Melaleuca rhaphiophylla*) with an understorey of flooding tolerant herbaceous perennials. Common species of this understorey included *Scirpus maritimus, Baumea juncea, Gahnia trifida* and *Sporobolus virginicus*. Soils of this region tended to be alkaline, highly organic, greyish in colour, sandy loams and very shallow over a limestone base. Species diversity was low and the infestation by introduced weeds was low.

Upland areas of sandy, slightly alkaline, yellowish soils of moderate depth and degree of leaching were dominated by Tuart (*Eucalyptus gomphocephala*). Areas of slightly acidic soils of greater depth and degree of leaching were dominated by a mixed Banksia—Tuart community. *Xanthorrhoea preissii* and *Hibbertia hypericoides* were widespread understorey species while species such as *Mesomelaena stygia, Scaevola canescens* and *Dryandra nivea* were restricted to areas of the mixed Banksia—Tuart Woodland. Understorey species diversity was highest in areas of the mixed Banksia—Tuart Woodland and was inversely related to the degree of weed infestation.

Control of the degree of inundation in the lowland areas and weed control measures for upland areas appear most urgent requirements for maintenance of the natural status of the Star Swamp bushland.

Introduction

Star Swamp is a wetland area within a region of undeveloped bushland located in the Perth metropolitan suburb of North Beach, Western Australia (31°51'S, 115°45'E) (Fig. 1). The swamp is a fresh water body, 4 ha in area, and is surrounded to the north, east, and south by approximately 90 ha of a mixture of woodland communities.

The area is situated approximately 600 m from the Indian Ocean on Spearwood Dune System soils (Bettenay *et al.* 1960). The wetlands would appear to have developed as an interdunal depression or possibly as a result of past marine activity in the zone between the Quindalup and Spearwood Dune Systems. Upland areas of the Spearwood System consist of a core of aeolianite with a hard capping of secondary calcite overlain by variable depths of yellow and brown sand (McArthur and Bettenay 1960). Originally the material was calcareous throughout but leaching of the surface soils has removed carbonates from the upper horizons to be precipitated below to form layers and columns of hard compact limestone.

The Spearwood dunes have had a complex history, being subjected to both deposition and later erosion. Much of the western surface sand has blown inland and, in conjunction with deeper leaching of the eastern region, has formed deep soils designated as the Karrakatta Soil Association (Seddon 1972). In the natural state this soil association supports a tall open forest of Tuart (*Eucalyptus gomphocephala*), Jarrah (*E. marginata*), and Marri (*E. calophylla*). In the western portion of the Spearwood System, the dunes are generally younger and the soils are shallower. This soil type has been referred to as the Cottesloe Soil Association (Seddon 1972). These soils carry much the same species composition as the deeper Karrakatta soils, however, Tuart is much more common than Jarrah and Marri. It is only on the Cottesloe soils that Tuart is found in pure stands (Seddon 1972).

Star Swamp and its surrounding bushland occur on the soils belonging to the Cottesloe Association. However, while Seddon (1972) states that the main plant formations of these soils are Tuart-Jarrah-Marri tall open forest or a closed heath, the presence of species of the *Banksia* woodland formation in the bushland at Star Swamp could indicate a much deeper soil profile (Bell *et al.* 1979). A woodland dominated by *Banksia attenuata*, *B. menziesii* and *Casuarina fraserana* is more typical on the deeper, leached soils of the older Bassendean Dune System (Seddon 1972).

Major objectives of the present study included an analysis of the stratal components of plant communities of the wetland and their immediate surrounding upland in relation to some environmental, edaphic and anthropogenic factors and the establishment of base-line data to develop a management programme for maintenance of this metropolitan bushland region.

Tree stratum

Methods

The Star Swamp bushland study area was gridded into ¼ ha square blocks (Fig. 1). The sampling grid of eleven rows each of six blocks contained a diversity of vegetational, environmental, edaphic and anthropogenic characteristics and was chosen for intensive analysis. The rows were numbered from north to south. Blocks within the rows were numbered west to east. The most northwest block (1,1) was a residential block and was therefore not considered. Also blocks (10,1) and (11,1) were so greatly disturbed that it was considered that data gained by sampling would not have added substantial information to the analysis of the area.

Maximum, minimum and mean elevation data for each block were approximated by superimposing the grid area on a topographic map. The mean elevation data were used to produce a contour computer map of the topography of the Star Swamp grid area (Fig. 2).

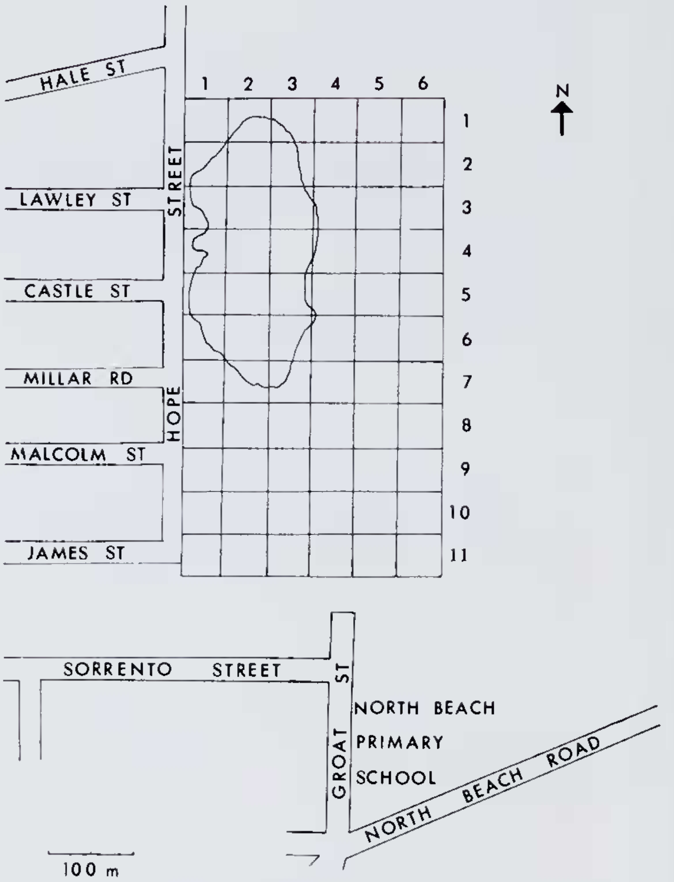

Figure 1.—Sampling grid for the Star Swamp bushland study area of North Beach, Western Australia. Approximate location of the 2 m contour is outlined.

In each block, all stems ⩾ 4 cm diameter at breast height (dbh) were identified to species and the dbh was recorded. In instances where a tree branched from the base, each branch was measured and recorded separately. In addition each stem (or basal branch) was noted as alive or dead. A block importance value for each tree species was determined as the mean of the relative basal area and relative density percentages. Importance values for each block were used as the input data for a Polar Ordination (Cottam *et al.* 1973) using the Ordiflex Program of the Cornell Ecology Series (Gauch 1973).

Tree diameters were sorted into size-classes. Each class covered 12 cm. Where a multi-branched tree was measured the size-class was determined by summing the individual branch measurements. Size-class analysis was performed on all trees of the intensive study area and then on only those trees recorded as alive. The relationship between tree size and the number of individuals in size-classes was tested against the negative exponential model (Johnson and Bell 1975). The quality of the statistical fit was assessed by a Kolmogorov-Smirnov test (Snedecor and Cochran 1967).

Results and discussion

Fourteen tree species were identified in the intensive study area. The most common tree species were *Melaleuca rhaphiophylla* (Swamp Paperbark), *Eucalyptus gomphocephala* (Tuart), *Banksia attenuata* (Narrow-leaved Banksia), *Banksia menziesii* (Menzies' Banksia) and *Eucalyptus marginata* (Jarrah). Other species reaching tree size (⩾ 4.0 cm dbh) in the study area were *Acacia cyclops, Acacia saligna, Banksia grandis, Casuarina fraserana, Dryandra sessilis, Hakea glabella, Jacksonia furcellata, Jacksonia sternbergiana,* and *Olea europaea.*

The analysis of the tree stratum was centred on the distribution and habit of four of these species, namely *Melaleuca rhaphiophylla, Eucalyptus gomphocephala, Banksia attenuata* and *Banksia menziesii,* since they were the most common by far and may be considered as indicator species for certain environmental and edaphic conditions.

Melaleuca rhaphiophylla was confined to the northwestern portion of the study area, dominating blocks 1-3 of rows 2-7. In the 18 blocks where *Melaleuca rhaphiophylla* was present, the Paperbark density ranged from 380 to 4 stems ha^{-1} and averaged 184 stems ha^{-1}. Basal area for *Melaleuca rhaphiophylla* averaged 19.7 m^2 ha^{-1} but reached a maximum in block (3,2) of 58.6 m^2 ha^{-1}. The first axis of the polar ordination (Fig. 3a) tended to separate those blocks dominated by Paperbark from the other blocks (Fig. 3b).

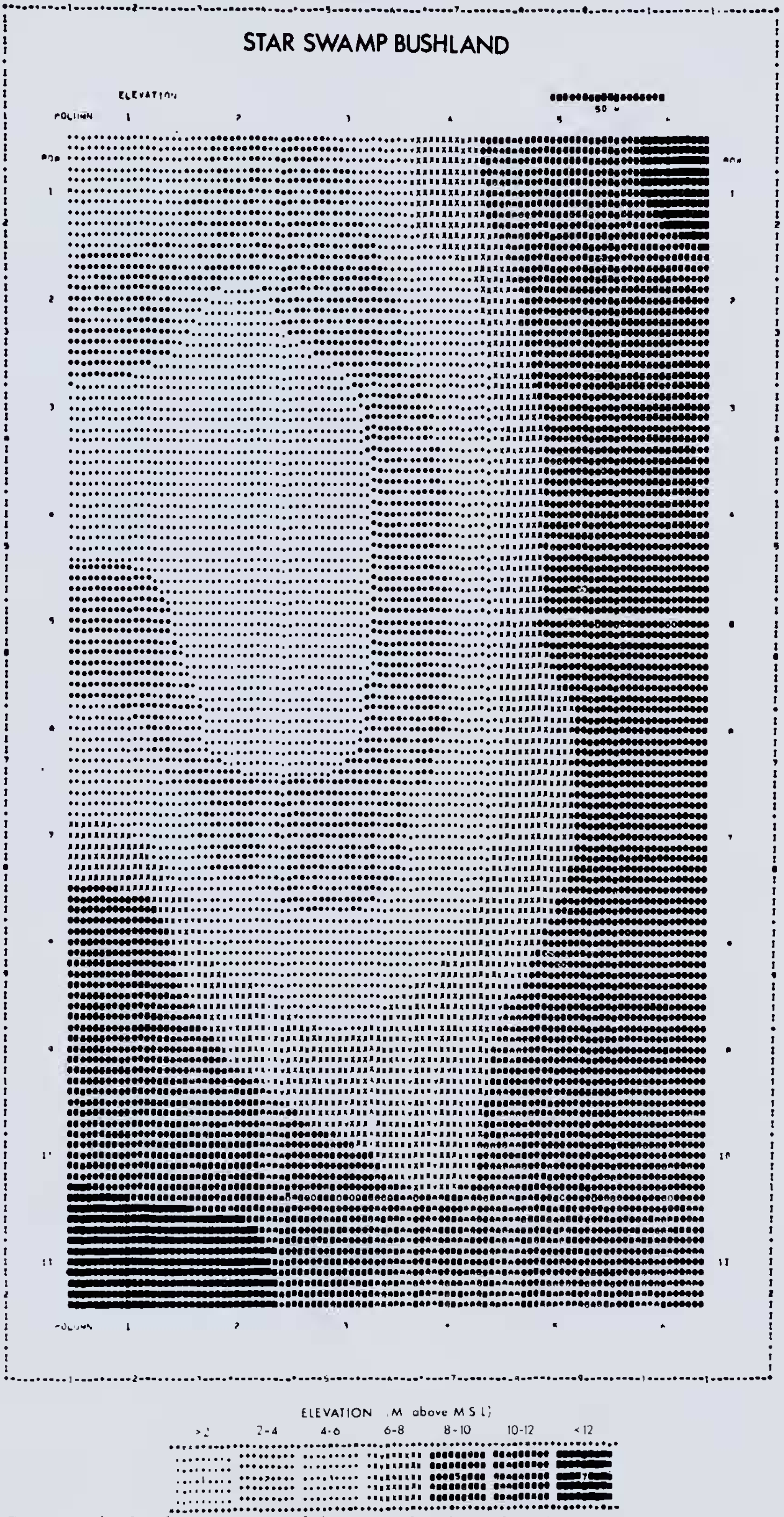

Figure 2.—Computer simulated contour map of the mean elevations of the blocks of the Star Swamp study area.

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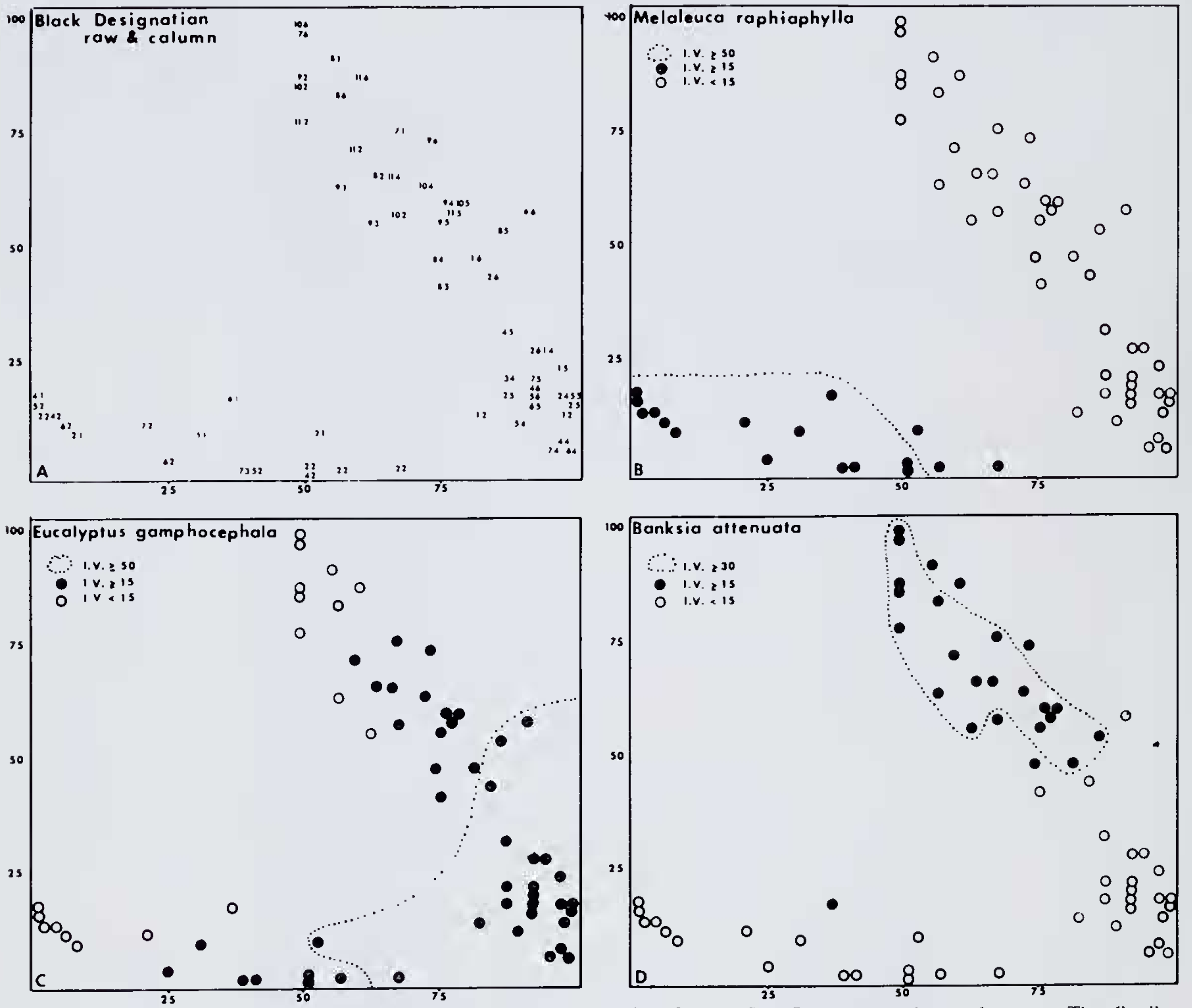

Figure 3.—Polar ordination of the overstorey importance value data for the Star Swamp intensive study area. The distribution of the 63 samples in the first two axes of the polar ordination (A) and degree of dominance by *Melaleuca rhaphiophylla* (B), *Eucalyptus gomphocephala* (C), and *Banksia attenuata* (D) are represented.

Eucalyptus gomphocephala was the most widely distributed of the tree species of the study area, being present in 45 of the 63 sampling blocks. Tuart predominated in the blocks to the east and north-east of the Paperbark-dominated region. Average Tuart density was 34 stems ha^{-1} and the average basal area for this species was 11.57 m^2 ha^{-1}. Basal area totals for Tuart were therefore approximately 60% of the Paperbark totals even though the tree density values for *Eucalyptus gomphocephala* were less than 20% of the *Melaleuca rhaphiophylla* density values. Blocks dominated by Tuart were positioned at the opposite end of the primary axis of the polar ordination from the Paperbark-dominated blocks (Fig. 3c).

Banksia attenuata and *Banksia menziesii* were concentrated in the southern half of the study area. In addition *Banksia attenuata* occurred on the eastern boundary of the study area. *Banksia attenuata* was predominant but generally shared the important values with *Banksia menziesii, Eucalyptus gomphocephala,* and *Eucalyptus marginata*. *Banksia attenuata* was recorded from 28 blocks (Fig. 3d). In these 28 study blocks, the species had an average density of 86 stems ha^{-1} and an average basal area of 3.29 m^2 ha^{-1}. *Banksia menziesii* also occurred in each of these blocks and averaged 55 stems ha^{-1} and 2.35 m^2 ha^{-1} for density and basal area respectively.

Ordination of the tree stratum importance value data distributed the blocks into three rough groupings. The density and distributions of the dominant tree species on the ordination suggested the designation of three communities: (1) a Paperbark-dominated woodland, incorporating the blocks dominated by *Melaleuca rhaphiophylla*; (2) a Tuart-dominated woodland, including blocks dominated by *Eucalyptus gomphocephala*; and (3) a mixed Banksia-Tuart woodland incorporating the remaining blocks of predominantly *Banksia attenuata* and *E. gomphocephala* with inclusions of *E. marginata* and *B. menziesii* although clinal relationships between the blocks are apparent. The positions of blocks (1,6), (2,6), (6,6), (8,3), (8,4) and (8,5) illustrate this point. They appear as transition plots midway between more easily classified blocks of the Tuart and the mixed

Banksia-Tuart communities. Also noteworthy were blocks (1,2) and (6,1) which contained two rather distinctively different assemblages of plants and were artificially combined because of the position of the sampling grid. General appearance of the three communities is depicted in Figure 4.

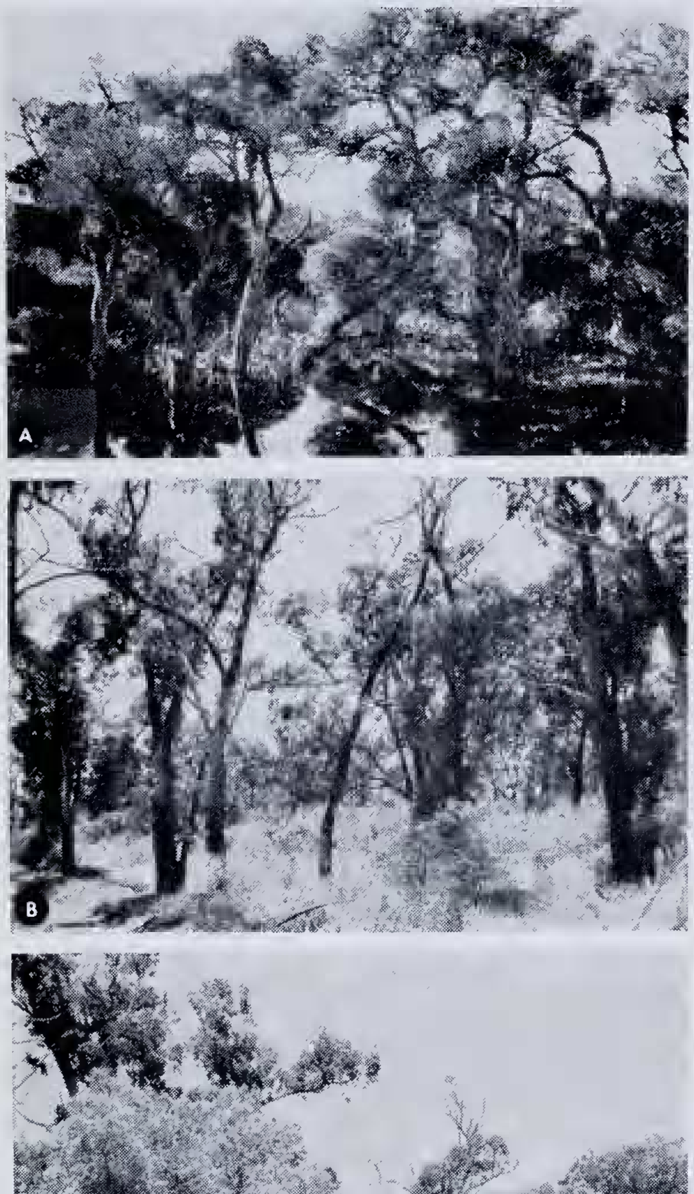

Figure 4.—General habitat appearance of the communities of the Star Swamp intensive study area, including the Paperbark woodland (A), the Tuart woodland (B) and the mixed Banksia-Tuart woodland (C).

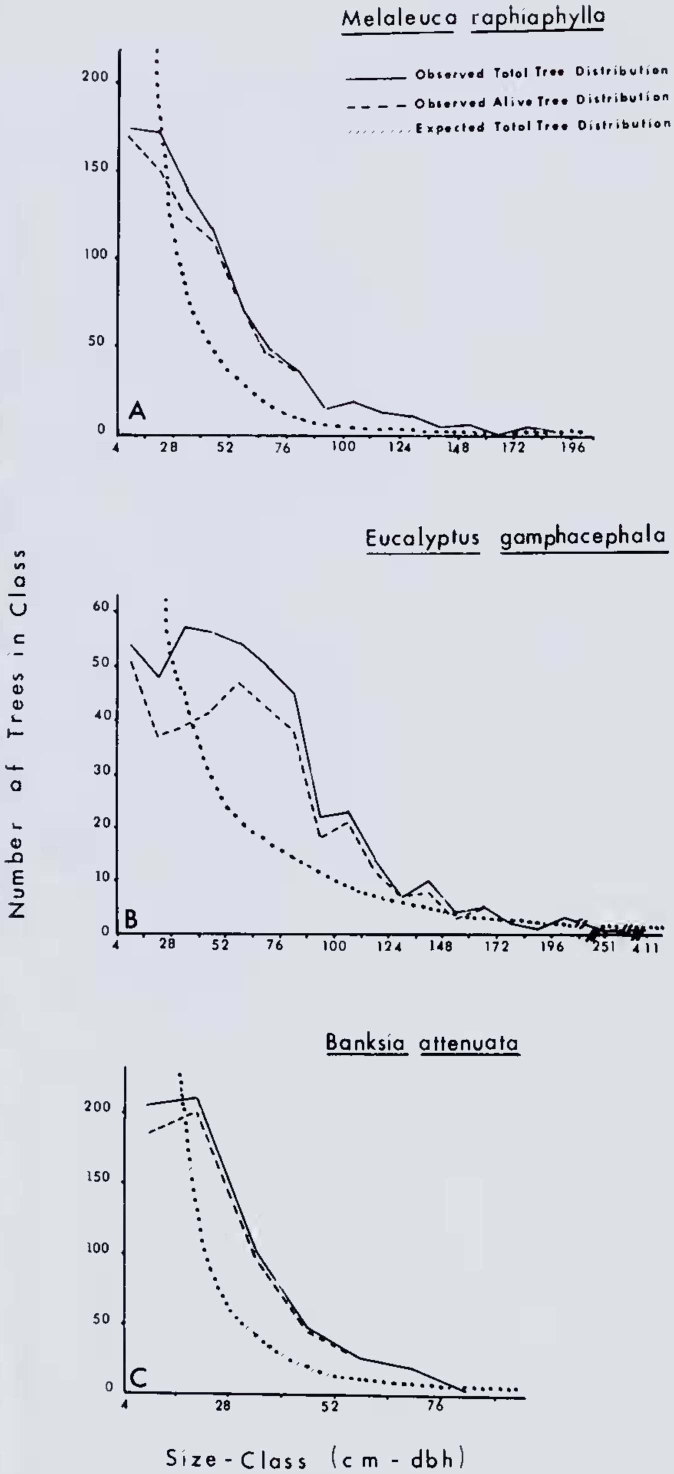

Figure 5.—Size-class analysis of the populations of *Melaleuca rhaphiophylla* (A), *Eucalyptus gomphocephala* (B), and *Banksia attenuata* (C). The observed total tree distribution, the distribution of the population of living trees separately and the expected total tree distribution using the negative exponential model are illustrated for each species.

Analysis of the tree stratum of the Star Swamp bushland by size-classes revealed additional information. Generally the numbers of trees within the diameter class decreased with increasing size (and presumably age) (Fig. 5). The relationship was, however, not linear and conformed more closely to the negative power curve indicating decreasing mortality with increasing age (Johnson and Bell 1975).

For all of the major species in the study areas, the numbers of trees in the smaller (and presumably younger) size-classes, were considerably less than

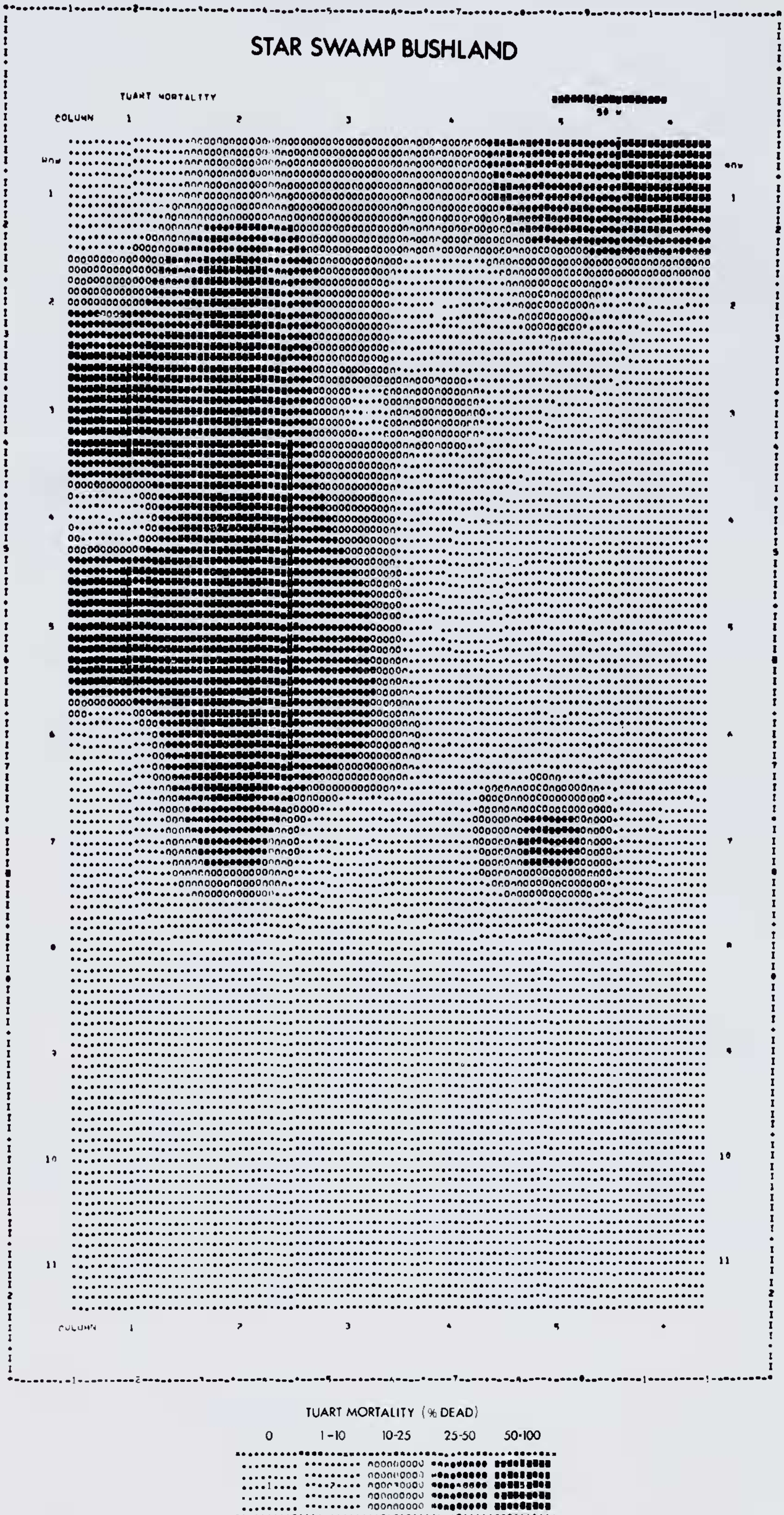

Figure 6.—Tuart mortality contour map. Simulated computer map based on the percentage of the tree basal area recorded as dead in each block.

expected. The reduced numbers of trees in the small size-classes, indicated that conditions for seedling establishment have been less than optimal in the recent past. The large disparity between the observed and expected values in the small size-classes generally affected the analysis of the quality of the statistically fitted curves and the negative exponential model. None of the curves were statistically significant indicating that factors in addition to age need to be considered in the distribution of size-classes at Star Swamp.

The less than expected total tree numbers in the smallest size-classes probably reflects reduced seedling establishment. The difference between the total tree distribution value and the alive tree value for a given tree size-class, however, reflects the mortality of that particular class. Only the smallest size-class in the *Banksias* reflects a large difference (Fig. 5c). The mortality of the younger *Banksias* is most likely the result of greater fire frequency in the recent past. Although no precise records have been kept, local residents report that in the recent past, the upland portions of the natural area have experienced numerous burns. These frequent fires could be the reason for the large numbers of dead standing stems of the smallest size-class.

Tuart mortality is apparent in all but the very largest of the classes (Fig. 5b). The increased frequency of fires could have had an effect on the youngest trees but death in the older size-classes is probably attributable to a more complex set of circumstances. Metropolitan populations of *Eucalyptus gomphocephala* are generally deteriorating (Beard 1967). Few seedlings can be found and the established trees show progressive deterioration of the crown ultimately resulting in death. The progressive dieback of the crown and the inability to restore foliage is caused by leaf-chewing phasmids and other defoliating insects thought to be correlated with the reduction of bird populations throughout the metropolitan area (Beard 1967). A second major insect enemy is the Tuart bud weevil (*Haplonyx fibialis*) which bores through the unopened young buds to lay an egg. The insect then cuts off or rings the bud at its base so that it either falls directly or is later dislodged by the wind. On contact with the soil surface moisture the bud tissue softens and becomes more easily available to the growing larvae. The ground beneath Tuarts in late summer is often littered with fallen buds that have failed to open, each drilled by a small hole (Seddon 1972).

Most upland Tuarts in the bushland at Star Swamp have the stag-horned appearance of a dying crown. Average percentage dead tree material in the sampling blocks with a minimum elevation above 2 m was 9%. By far the greatest Tuart mortality, however, occurs in the lowland blocks surrounding the swamp (Fig. 6). In blocks where the minimum elevation was less than 2 m but greater than 1 m, the percentage of the Tuart basal area recorded as dead was 19%. In the study blocks where minimum elevations were below 1 m, the percentage of dead tree material for Tuart averaged 82%.

Paperbark also showed mortality in many of the smaller size-classes (Fig. 5a) indicating causes of death were not restricted to the smallest and presumably youngest trees. *Melaleuca rhaphiophylla* did not occur in blocks where the minimum elevation

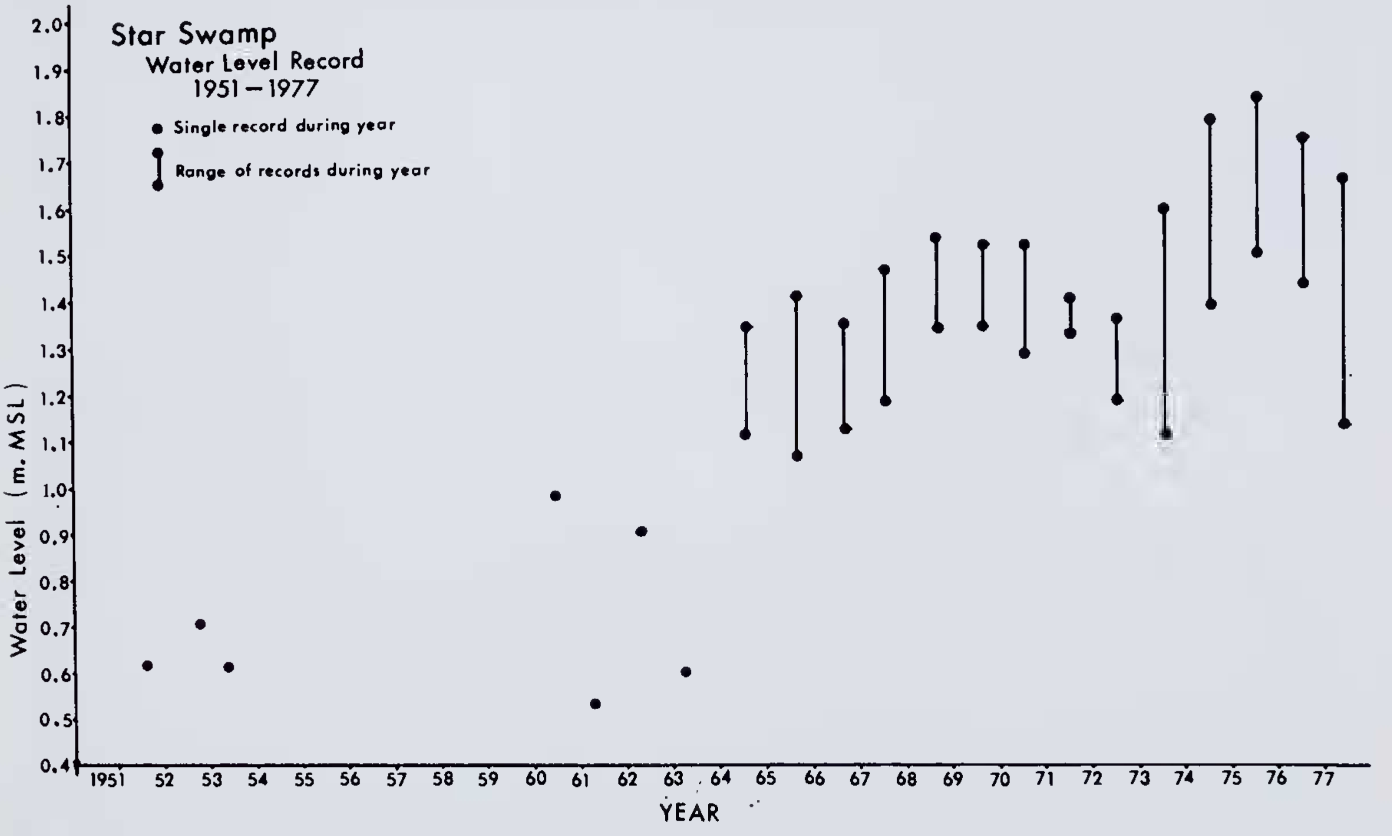

Figure 7.—Water level records for Star Swamp. Single winter records for earlier years and the range of water level values for multi-record years are plotted for the period of record. The data were supplied by the Division of Ground Water of the Metropolitan Water Board.

was greater than 2 m, but for blocks less than 2 m but greater than 1 m minimum elevation the percentage mortality among the Paperbarks was 0%, while blocks with minima below 1 m, percentage mortality was 7%. The data on percentage dead tree material for Tuart and Paperbark suggest that habitat conditions relating to elevation in the swamp region are affecting tree survival as well as seedling establishment.

Data on water level in Star Swamp have been collected at irregular intervals since establishment of a water level observation bore on the eastern margin of the swamp in 1951 (Fig. 7). Generally there has been a rise in water levels over the period of record, with maximum levels reached in the winter of 1975. This rise in water levels at Star Swamp is in conflict with the general trend observed for other Perth metropolitan water bodies (Burton 1976). Perth lake water levels were generally at minimum levels in the early sixties and then again in the mid-seventies. Peak water levels were recorded in the late sixties. Star Swamp levels rose during the wet rainfall years of the late sixties but instead of falling again during the seventies, the swamp water levels continued to rise. Burton (1976) hypothesizes that this rise of water tables in Star Swamp is a consequence of vegetation clearing and residential development to the west, and to a limited extent immediately north of the swamp.

The water run-off from the storm water drains has probably caused the high water levels in Star Swamp and maintained the lake through the summer drought period. The effect of permanent flooding on soil oxygen levels has probably cause the mortality observed in the lowest elevation Tuarts and Paperbarks. Seddon (1972) states that Paperbarks can tolerate winter flooding but rooting zones must be free from saturation for certain periods during summer. The general avoidance of habitats having periodically flooded soils by Tuarts would indicate that the species would be even more intolerant of prolonged saturation than the Paperbarks. The general increase in percentage mortality with decreasing elevation at Star Swamp seems to result from the maintenance of high water levels in the lake by runoff from the developed area in the western slope of the catchment. Further increases in water levels at Star Swamp could eventually lead to the death of all trees such as has occurred at Lake Claremont, formerly Butler's Swamp (Evan and Sherlock 1950).

Edaphic conditions

Methods

Soil properties for each of the 63 blocks were determined from samples taken from the centre of the sampling block. Samples were taken to a maximum depth of 50 cm from the surface and depending on colour differences, one to three depth samples were returned to the laboratory for analysis. The air-dried samples were tested for colour, organic matter, texture and pH. Colour descriptions for all depth samples were made using the Munsell colour notations (Munsell 1954). Organic matter content of the block samples was determined by loss on ignition (Bear 1964). Textural analysis for soil particle size distribution employed the Buoyoucos hydrometer method (Buoyoucos 1936). Soil pH was determined in 5:1 distilled water to soil mixtures using a glass electrode. Samples were prepared 24 hr preceding measurement and placed in a mechanical shaker for the final 45 minutes. Replicate samples of all measurements were averaged.

Results and discussion

Soil conditions determined for the intensive study blocks were presented on the vegetation polar ordinations to observe the relationship between the edaphic conditions and the dominant species of the region (Fig. 8). Soils colours for all levels of the block samples were analysed and appeared to represent two distinct groups. The swamp soils, in grey tones (2.5 YR) throughout the profile, range to the darker values and more subdued chromas with depth (Fig. 8a). Because of the general similarity of the soil profile in these immature entisols, only the upper horizon data has been presented. The remaining soils of the study area were in brownish tones (10 YR), with the top soils mainly recorded as dark browns or dark grey brown. As depth increased in these upland sites the colour changed to lighter browns and grey browns until the deeper soils reflected a yellowish-brown colour value and hue.

The soils of the *Melaleuca*-dominated blocks were again different from the remainder when percentage organic matter and textural percentages were measured (Figs. 8b and 8c). Swamp block soils were generally 3 to 5 times as high in percentage organic matter when compared to the upland block samples. All samples of the area were sandy textured but the greater content of clay- and silt-sized particles in the swamp soils were classified as loam sand or sandy loam and the soils in blocks above the influence of flooding levels were classified as sand (Buckman and Brady 1969).

Unlike the previous edaphic conditions which separated into two major groups, soil pH tended to separated into three groups. The swamp blocks dominated by *Melaleuca rhaphiophylla* had slightly alkaline top soils with pH values generally in the 7.5 to 8.0 range (Fig. 8d). Soils of the Tuart woodland blocks generally were in the 7.0 to 7.5 range. The blocks of the mixed Banksia-Tuart woodland community had soil pH values in the slightly acidic 6.0 to 6.5 range. Soil pH was the only edaphic condition which could be related to the three community partition of the tree stratum.

Generally the soils of the Spearwood Dune system are weakly leached with low calcium levels, high iron content, and have weakly acid pH conditions (Havel 1976). In a study of the relationship of broad soil and vegetation groupings at a slightly more northerly Spearwood soil location at Gnangara, Hopkins (1960) recognized four site types based on differences in leaching of the topsoils and the location of depositional limestone. (1) Poor *Banksia* scrub (*Banksia attenuata*, *B. menziesii*, and *B. ilicifolia*) on deep sands with a deposition horizon more than 3 m from the surface. (2) Jarrah-Marri forest (*Eucalyptus marginata* and *E. calophylla*) on flats with a deposition horizon within 2 m of the surface. (3) Tuart forest (*Eucalyptus gomphocephala*) on yellow sand over limestone. (4) Paperbark (*Melaleuca preissiana*) on swampy areas.

The mixed *Banksia-Tuart* woodland designated blocks at Star Swamp could probably be interpreted as an amalgamation of the first two site types of Hopkins. The more acid conditions of the top soils indicated leaching of the calcium to greater depths

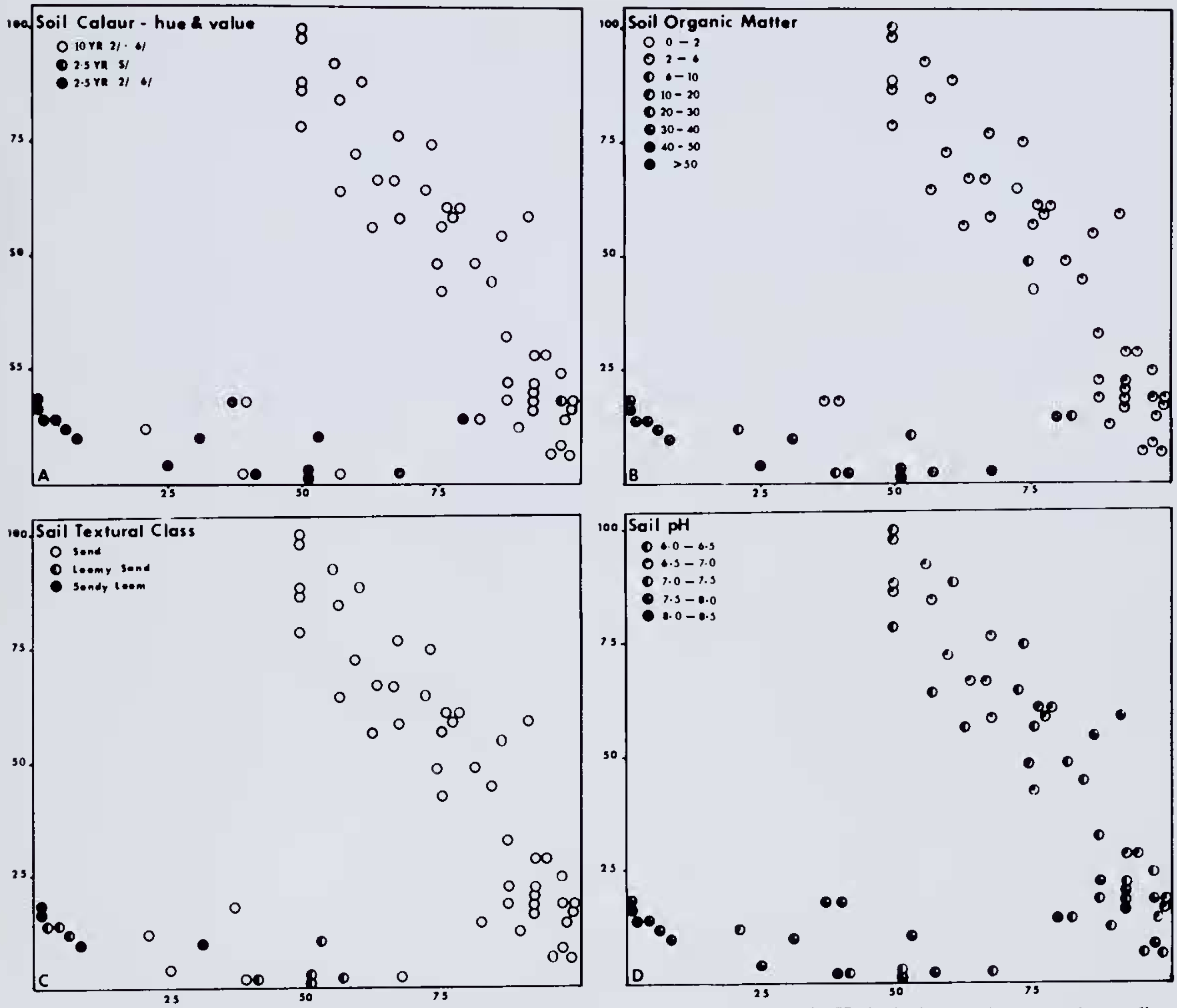

Figure 8.—Edaphic conditions of soil colour, soil organic matter, soil texture and soil pH drafted onto the vegetation ordination. For value of each parameter refer to legends on each graph.

than in the Tuart and Paperbark communities. The slightly alkaline conditions of the Tuart blocks at Star Swamp probably indicated that the limestone is relatively close to the surface. Depositional horizons in the Paperbark community are quite near the surface and top soils with pH levels greater than 7.5 indicate higher calcium carbonate levels.

The vegetation communities at Star Swamp therefore also represent a cline of increasing profile depth and leaching, but the generally high pH levels probably indicate that the profile depths may not be as great as those of the Gnangara region.

The first ordination axis appears to separate the vegetation at Star Swamp into areas depending upon the tolerance of species to flooded conditions. The second polar ordination axis appears to be a gradient of leaching from the weakly-leached areas in the lower elevations to the more strongly-leached sands of the mixed Banksia-Tuart woodland. The major environmental gradients involving moisture and the degree of soil leaching confirm previous observations on tree species distribution on the Spearwood soils of the Swan Coastal Plain (Havel 1976).

Perennial shrub and herb stratum

Methods

The perennial shrub and herb stratum at Star Swamp was quantified by sampling eight 4 m^2 quadrats in each of the 63 sampling blocks. The quadrats were placed along a transect from one corner across the centre to the far corner. Within each quadrat the shoot cover percentage of each species was recorded. Samples within each block were averaged. Understorey species cover values for the most important 61 species were used for Polar Ordination (limited computer storage required reduction of species numbers to 61; the matrix was reduced using the eident value concept of Dale and Williams (1978) which determines importance as the ability of a species to differentiate samples in subsequent ordinations). Understorey species richness and species diversity for each block were determined. Richness was merely the number of species present in the plot. Species diversity, which takes into account both the number of species and the equitability of their arrangement, was assessed using the Shannon-Wiener index (Shannon and Weaver 1944, Pielou 1966).

A subjective estimation of the degree of adventive weed infestation was also recorded for each block. This estimation index was based on a rank of numbers from 0 to 10, with 0 indicating no infestation, 5 indicating that approximately 50% of the area was under weed cover, and 10 representing total infestation of the sample block.

Results and discussion

The polar ordination of the block samples of the understorey stratum at Star Swamp resulted in a general clustering of the upland blocks (Fig. 9a), regardless of the overstorey composition which was separated from those samples from the Paperbark community (Fig. 9b). The wide separation of the blocks in the Paperbark community was caused by the restricted distribution of a number of wetland species. *Scirpus maritimus* (Fig. 9d) occurred throughout the Paperbark blocks but *Gahnia trifida* (Fig. 9c), *Typha orientalis* (Fig. 9e), *Baumea juncea* (Fig. 9f), *Sporobolus virginicus* (Fig. 9g)and *Centella asiatica* (Fig. 9h) were species occurring in only selected locations in the swamp region. All are species tolerant of periodic flooding and good indicators of this severe habitat factor.

In contrast to the separation of the samples of the Paperbark-designated community, the samples of the remaining blocks were arranged together, indicating similar vegetative constitutions. A number of species were widely distributed in the upland areas and appeared in most samples. Among these species were

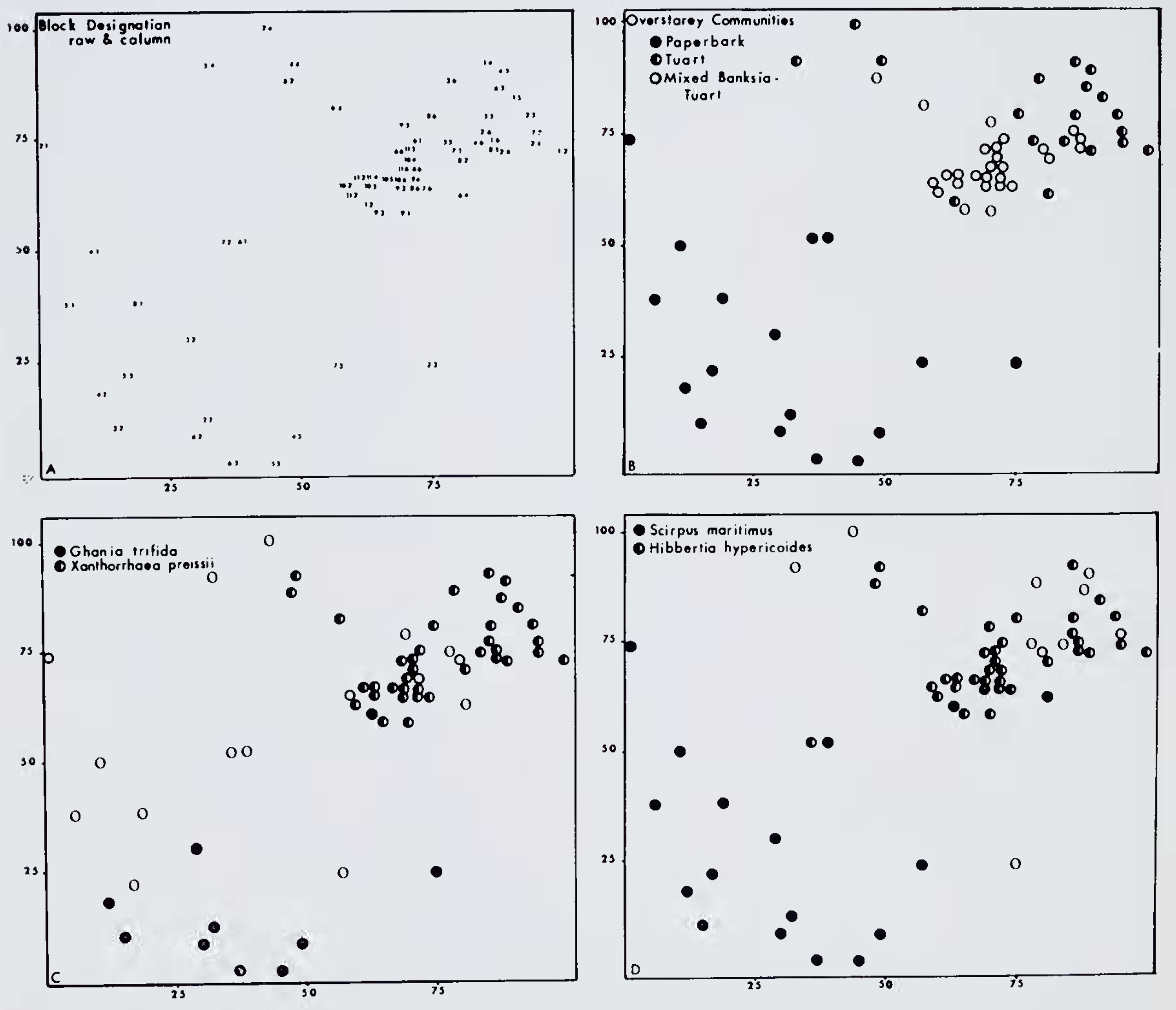

Figure 9.—Polar ordination of the understorey sample data from the Star Swamp study area. A. Row and column designation of each block for location of subsequent values. B. Overstorey community designation. C-H. Presence of designated species in block sample.

Xanthorrhoea preissii (Fig. 9c), *Hibbertia hypericoides* (Fig. 9d), a *Loxocarya* species (Fig. 9e), *Conostylis aculeata* and *Pelargonium capitatum*. Certain species, however, were restricted to the mixed Banksia-Tuart woodland regions. These were *Mesomelaena stygia* (Fig. 9f), *Dryandra nivea* (Fig. 9g), *Scaevola canescens* (Fig. 9h) and *Petrophile macrostachya*. None of the 61 species used in the ordination were restricted to Tuart overstorey blocks and the separation seemed to be based on differing cover percentages of a basic series of species. Of the 35 species rejected by the eident value system, only *Templetonia retusa* and *Melaleuca huegelii*, and seedlings of *Eucalyptus gomphocephala* and *Melaleuca rhaphiophylla* were found in the Tuart blocks but excluded from the mixed Banksia-Tuart areas. *Xanthorrhoea preissii* and *Hibbertia hypericoides* have previously been reported to occur on both shallow and deep soils of the Bassendean system (Havel 1976). At Star Swamp on soils of the Spearwood system, these two species occurred in a wide range of the upland blocks, further indicating their apparent broad range of ecological tolerance. Havel (1976) also states that *Xanthorrhoea preissii* is a good indicator of moist sites. None of Havel's dry site indicators occurred in the block samples. The areas of upland surrounding the swamp apparently lie in the moist end of the moisture continuum of habitats on sands of the Swan Coastal Plain.

A sub-group of five blocks, (4,4), (5,4), (7,4), (8,2), and (8,3), appears on the ordination separated from the major cluster of the upland block samples. These blocks differ primarily in large cover percentages of *Acacia saligna*, a species most commonly distributed at fringes of the swamp but occurring in the blocks designated as Tuart and Mixed Banksia-Tuart woodlands. *Acacia saligna* is generally widespread and also found in the wetter areas often on disturbed land (Seddon 1972).

Tabulating the species occurring in the three designated communities, we found that the Paperbark vegetation totalled only 31 species, of which 50% were restricted to the Paperbark swamp blocks. The species total in the Tuart blocks was higher at 51

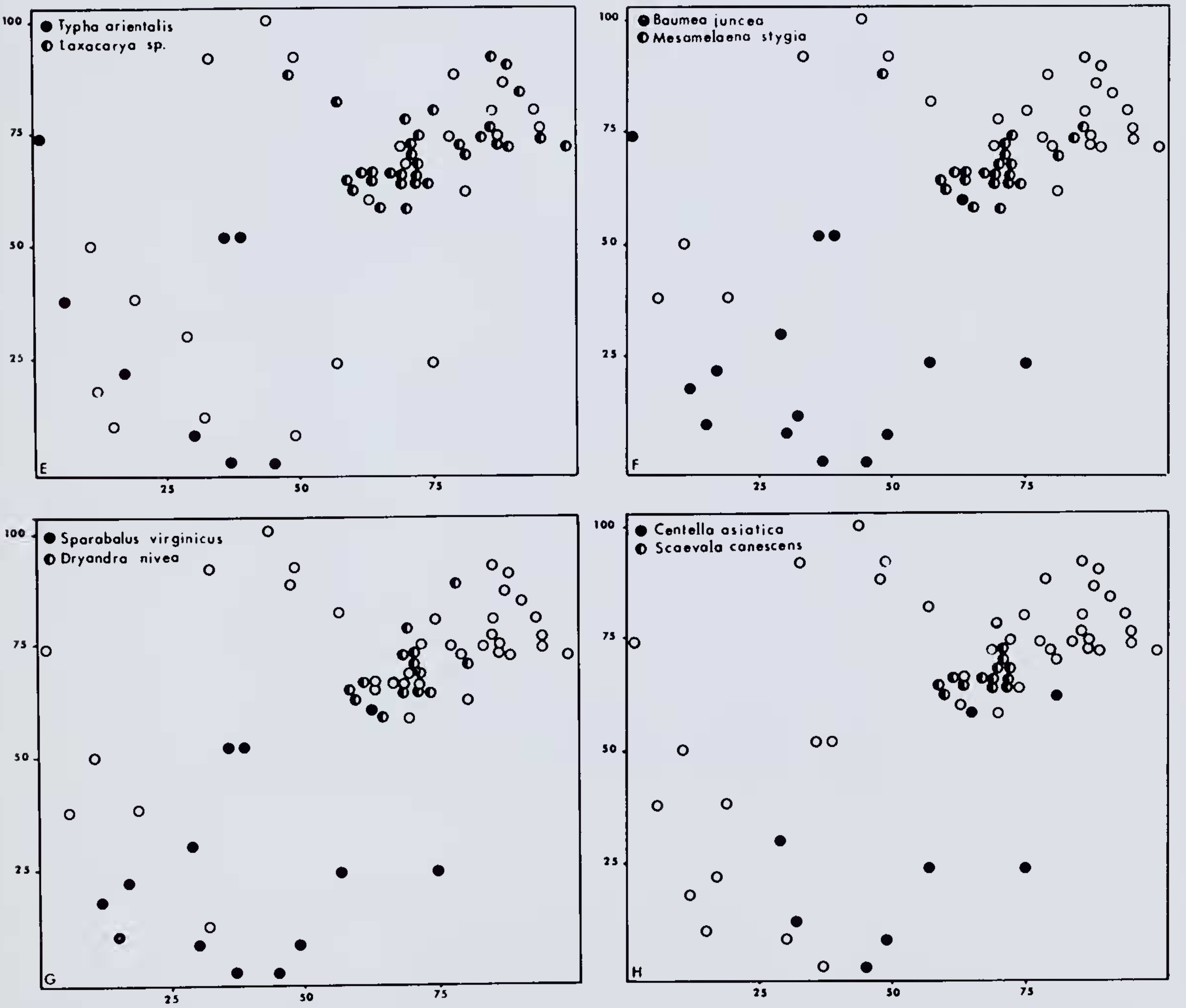

Figure 9.—continued.

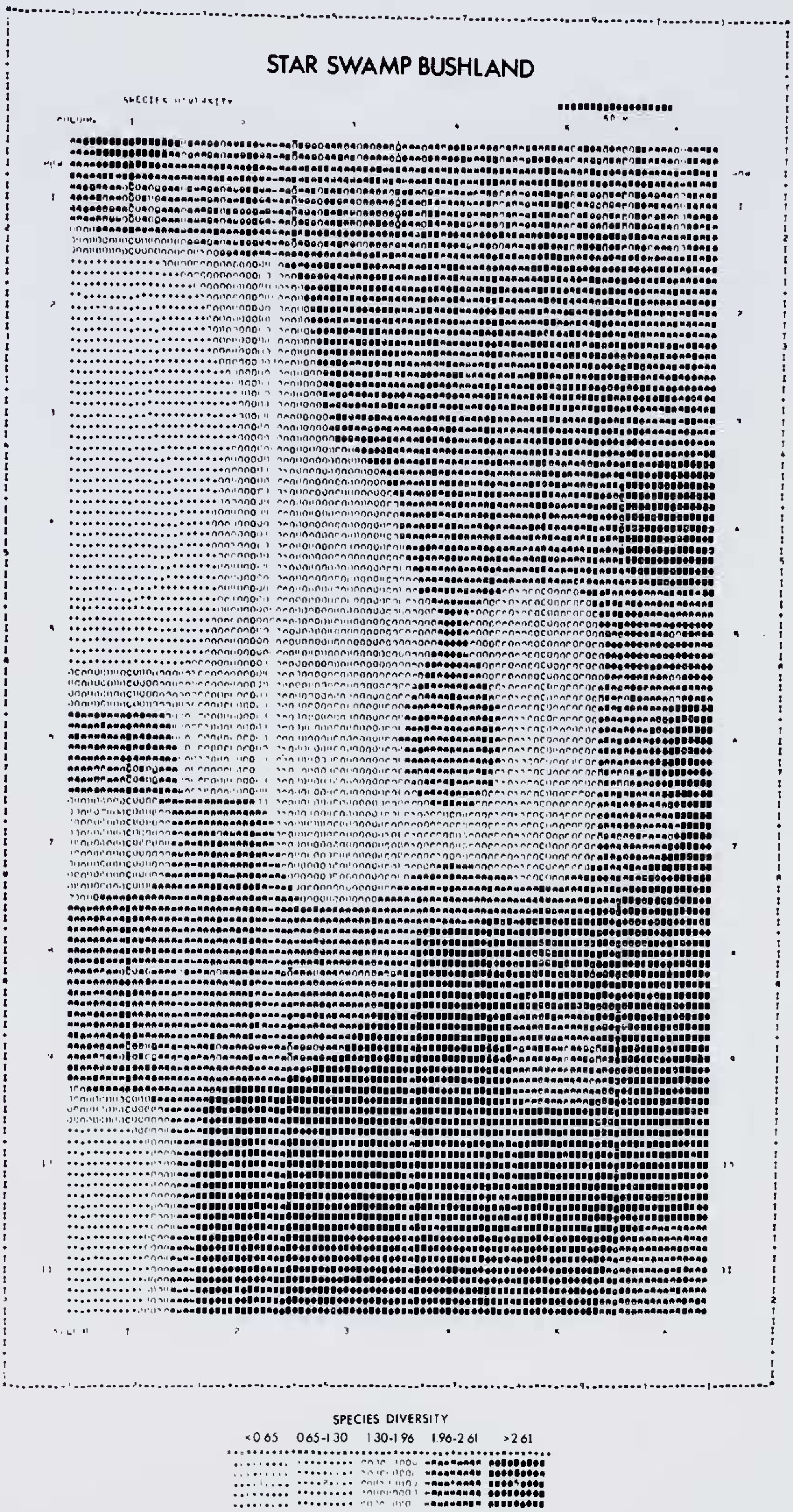

Figure 10.—Species diversity contour map. Simulated computer map based on the Shannon-Wiener index values for each block.

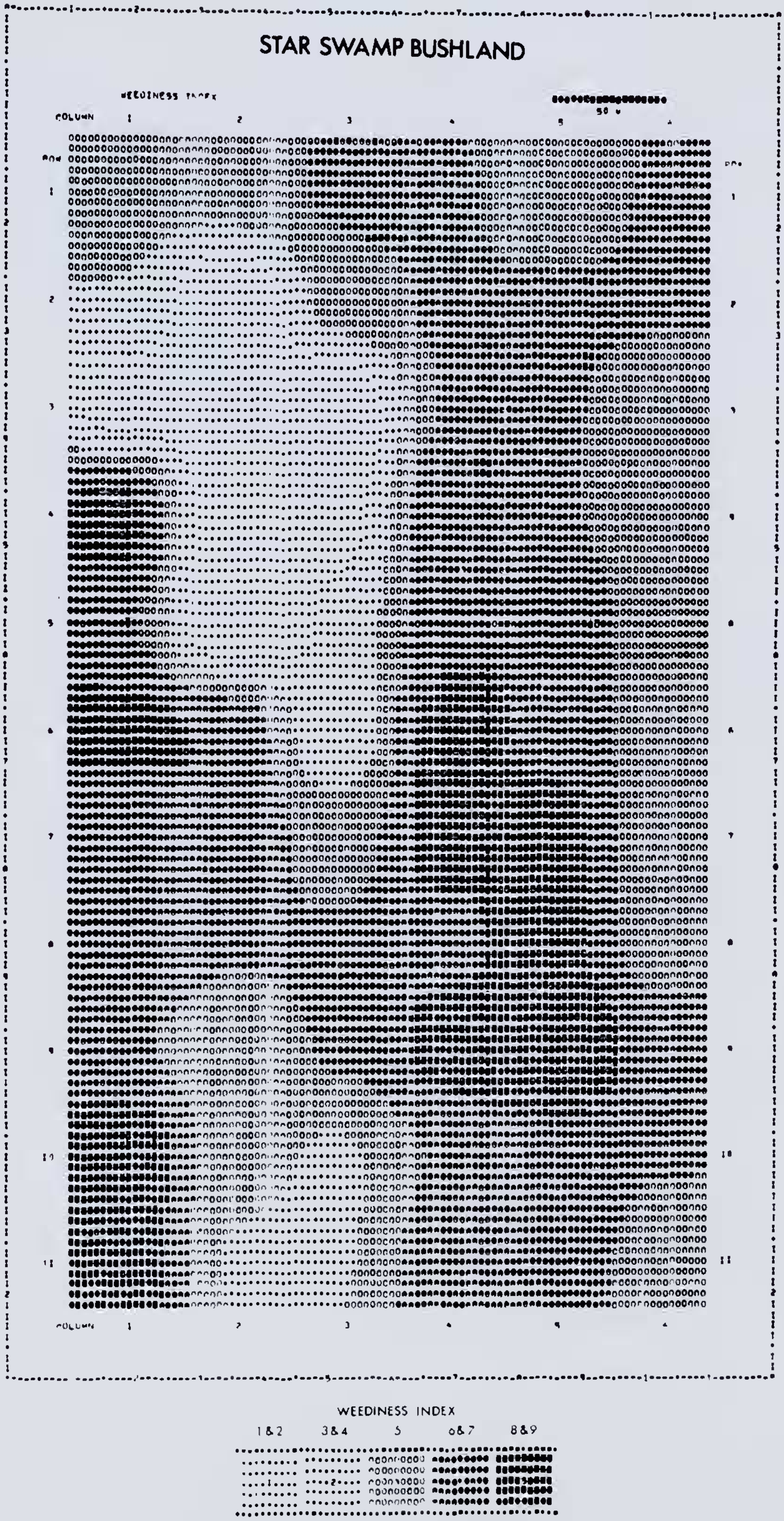

Figure 11.—Weediness index contour map. Simulated computer map based on the subjective weediness index value for each block.

species, but only 8% were recorded as restricted to this region. The mixed Banksia-Tuart understorey was richest with 73 species of which 31% were restricted to the region. When the community understoreys were compared it was evident that the shrub and herb strata of the Tuart and mixed Banksia-Tuart communities were most similar with 44 species shared or 55% of species in common. Species similarity in the understorey samples of the Paperbark and Tuart was next highest with 14 species shared or 21% of species in common. The Paperbark and mixed Banksia-Tuart woodlands were most dissimilar with only 11 species occurring in both regions or 12% of their species in common. In the understorey, therefore, there appears an intergrading continuum of species from the areas of Paperbark overstorey through the Tuart dominated regions to the leached-soil areas of the mixed Banksia-Tuart overstorey.

Generally the species richness and species diversity of the block samples increased with elevation (Fig. 10), Lowest Shannon-Wiener index values were calculated for the Paperbark swamp areas. The highest species diversity values occurred in blocks with an overstorey of mixed Banksia-Tuart. The correlation between species diversity and mean elevation was statistically significant ($r = 0.68$ $P < 0.05$). Areas of severe habitat conditions generally support fewer species (Bell 1980). The saturated soils of the swamp severely restricts the number of potential inhabitants in the low-lying blocks. Strong dominance by single species in areas of the swamp further restricts the Shannon-Wiener values by affecting species equitability. Upland areas contained more species and generally the cover values for species were more equitably distributed. It was apparent, however, that upland areas with infestations of exotic species had lower species diversity values. Species diversity was inversely related to the index of weediness derived from the percentage cover values for exotics for each block (Fig. 11). Correlations between the Shannon-Wiener index values and the subjective Weediness Scale values was also significant ($r = 0.25$, $P < 0.05$ for blocks above mean elevation of 2 m). Species diversity, therefore, is affected not only by severe conditions of soil saturation in the low elevational areas but also the percentage cover by the aggressive weedy species introduced from Mediterranean and South African areas. Weed concentration seems also to be negatively associated with canopy cover (Wycherley 1973). Although light interception values were not measured in the current study, the crown-affected areas of the Tuart woodland have severe infestation of weedy exotics. Understorey species distributions at Star Swamp respond to a number of habitat conditions. In the lowland areas, saturated soil and flooding are major factors affecting species survival. In upland areas, soil moisture, leaching as indicated by soil pH, and the presence of weeds all affect the distribution and association of understorey species.

Conclusions

The objective analysis of the vegetation in the intensive study area of the Star Swamp bushland provided confirmation of the earlier subjective assessment of Bell *et al.* (1979) of the presence of three basically different woodland communities. The composition of these woodland communities is strongly influenced by the tolerances of the species to the condition of the soils and the periodic lowland flooding. Weed infestations are having a severe effect on the species richness and diversity of the upland areas. Without adequate control measures the native Western Australian species will probably be replaced by exotic species adapted to high-light, disturbance areas. The integrity of the vegetation in the lowland areas seems dependent on the restriction of the increase in water levels experienced in the catchment since the establishment of residences on the western slope. Resident development of further areas in the catchment will increase drainage into the Star Swamp lake with the accompanying increase in Paperbark and Tuart mortality. Management of this metropolitan bushland for the continued enjoyment of the people of metropolitan Perth will require a sensible interaction of the use of fire, weed control measures, flood level and a basic knowledge of the ecological characteristics of the species inhabiting the region.

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